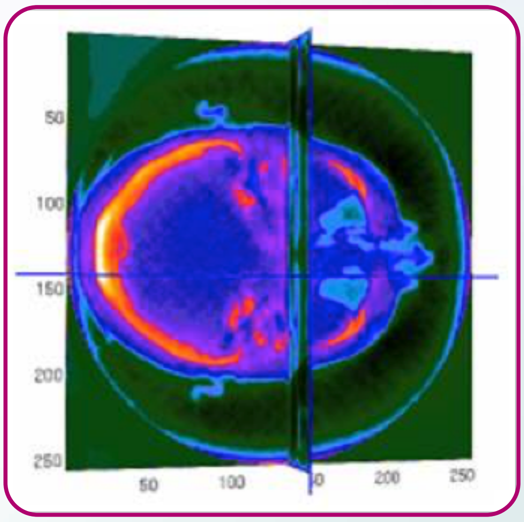
Saving Lives with Mathematics: Removing landmines and tumours



Left: Planar sensor for landmine detection. Right: Iterative reconstruction of Rando head model.

Researchers from the Engineering Tomography Lab (ETL) at the University of Bath are developing cutting edge mathematical techniques to improve the removal of both landmines and cancerous tumours. These two seemingly unrelated problems have a common challenge – they both require extremely accurate imaging techniques to enable detection. The researchers are working on two separate projects to improve the imaging of both landmines and tumours, with the prospect that their research will lead to many lives being saved.

Landmine Detection

It is estimated that there are around 110 million landmines which lie undetected worldwide, with the UN predicting that it could take 1,100 years to clear them all. If the scale of the problem wasn't bad enough, then there is the additional challenge that modern landmines are being made of plastic. This means that traditional metal detectors simply don't work, resulting in a desperate need for new solutions.

Researchers at the University of Bath have been granted funding from Sir Bobby Charlton's charity Find a Better Way to look into the problem of detecting plastic landmines. They have developed a new smart camera device which can scan the ground and produce a 3D image of what lies beneath. Their smart camera uses copper electrodes to first scan the ground to find out how insulating it is. Plastic is a good insulator, meaning that it can be detected by the smart camera using this method.

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It isn't however sufficient for a machine to simply beep like a metal detector when it thinks plastic is present. The insulating properties of the ground are too subtle and additionally there could be lots of buried plastic rubbish leading to frequent false positives and wasted time. Instead the researchers have used mathematical algorithms to take the electrical signal and convert it into a 3D image.

The process of turning the signal into an image relies on a branch of mathematics called tomography. One ingenious feature of the mathematical algorithm is that it uses what is known as machine learning. This means that every time the smart camera scans the ground the algorithm will learn from the new data and fine tune itself. This means that over time the smart camera images will constantly improve.

The smart camera has been proven to work successfully in a lab environment, and it is now being developed into a compact low cost device which can be used in the field.

Institute of mathematics & its applications

The researchers have also enabled the smart camera to detect traditional metal landmines, meaning that one single device can be used to detect both plastic and metal landmines.

In the future plastic detection technology may have other important applications in industries such as food manufacturing where it could be used to detect pieces of plastic which have accidentally entered the food chain.

Using tomography to fight tumours

The same research team at the University of Bath have also been working with CERN to create new medical imaging software called TIGRE which has the potential to significantly improve the treatment of cancer patients. It might seem surprising that CERN is working on cancer treatment when they are more famous for the Large Hadron Collider and the Higgs boson particle. In fact, many cancer treatments involve X-rays, Gamma Rays or beams of Protons, meaning that the particle research done at CERN is more relevant to treating cancer than many people realise.

At the moment, when a patient receives radiotherapy treatment, they will first be scanned in order to establish the position of their tumour, probably using a machine such as a CT (Computerised Tomography) scanner. In a CT scanner an X-Ray source rotates around the patient, effectively creating lots of different 2-D X ray pictures from different directions. This is where the mathematics of tomography comes in – it takes multiple 2-D X-Rays which have been taken from different sources and assembles them using mathematics into one coherent 3-D image.

> "improved algorithms mean that fewer X-Rays can be used in order to generate the same quality image"

Medical imaging and treatment of tumours using X-Rays is not new. However, the TIGRE software had made a number of important advances. Firstly, the mathematical algorithms have been significantly improved, meaning that they can be run around 1000 times faster than at present. This is important to clinicians working in hospitals as they will be able to obtain images in a matter of minutes rather than days.

Another advantage is that the improved algorithms mean that fewer X-Rays can be used in order to generate the same quality image. This means patients can receive a radiation dose which is 10 times less than that which is used at the moment.

One important area where these improved imaging techniques will be used is in the treatment of lung cancer. Unlike with a brain tumour, a patient cannot be kept completely still while their lungs are scanned as they still have to breathe. This results in noise in the image, potentially resulting in a dose of radiation being delivered to slightly the wrong place. This could be one of the reasons why there are comparatively poor outcomes for lung cancer treatment.

The improved mathematical algorithms which the researchers have come up with can take into account the movement of the patient and eliminate noise from the images. This will enable radiotherapy to be directed more accurately at lung cancer tumours, resulting in better outcomes for patients. In the future it is hoped that a combination of improved computing power and advances in the mathematical algorithms will enable scans to be so good that they could be used in real time by surgeons who are operating.

TECHNICAL SUPPLEMENT

At the heart of both of these pieces of research is the mathematical theory of Tomography. Tomography has applications far wider than medical imaging and can be used in areas as diverse as Space Science and Archaeology. The word Tomography comes from the Ancient Greek – Tomos meaning a slice or section and Grapho meaning to write. It is a way of taking slices of an object and then being able to recover what the whole object looks like just by using the slices which you have. For example, if you sliced up an orange from lots of different angles and took a 2D picture each time, using Tomography you can reassemble a 3D image of the whole orange.

In the example of a CT scan an X-Ray beam passes through the body from different angles and it is possible to measure how the intensity of the X-Ray beam changes along each of these lines. It is known that an X-Ray might diminish in intensity more if it passes through bone, than through soft tissue, giving a good idea of the type of material which might lie along the line of one particular X-Ray.

One of the most important equations in Tomography is the Radon Transform which was first invented by Johann Radon in 1917. The aim in Tomography is to find the inverse of the Radon Transform Equation which is done by using iterative algorithms. If you can invert the Radon Transform Equation, then you will be able to recover the complete 3-D image - in a way it is like putting the slices back together. Therefore one way in which researchers can improve medical imaging is by improving the algorithms which invert the Radon Transform.

Links

A more detailed explanation of tomography, but still aimed at the general public:
https://plus.maths.org/content/saving-lives-mathematics-tomography

A related Maths Matters Case Study:
https://ima.org.uk/678/scans-on-the-brain/

Academic References

Tholin-Chittenden, C., & Soleimani, M. (2017). Planar array capacitance imaging sensor design optimisation. IEEE Sensors Journal, [7956144]. DOI: 10.1109/JSEN.2017.2719579

Biguri, A., Hancock, S., Dosanjh, M., & Soleimani, M. (2016). TIGRE: A MATLAB-GPU toolbox for CBCT image reconstruction. Biomedical Physics & Engineering Express, 2(5).

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